Galileo: Metadata production and publication status

Galileo Project Team

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Outline

1. Metadata location and status
2. Content description
3. Benefit for science
4. Future updates
5. Conclusions

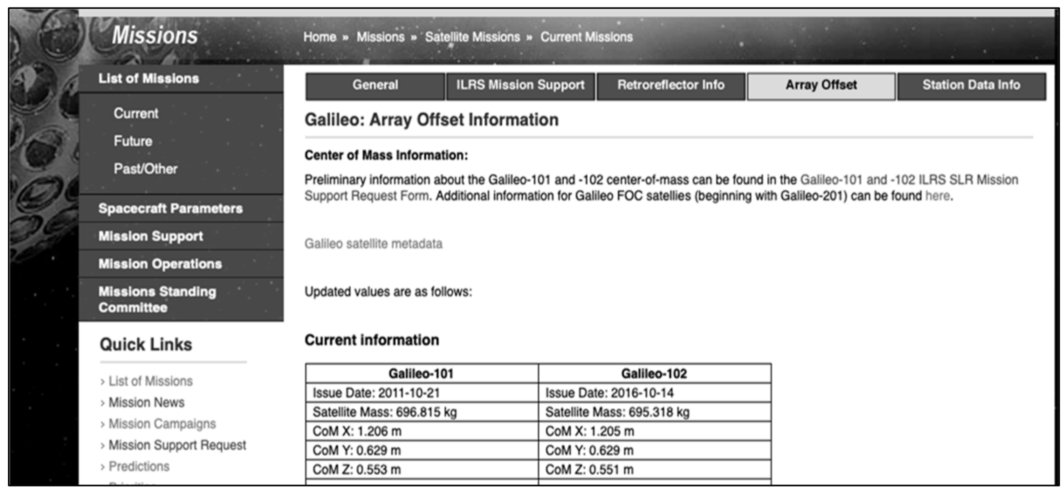
1. Metadata location

Satellite Metadata is released through two Web sites:

- Galileo Service Center (GSC) web site: full content
- ILRS web site: mass, center of mass and Laser Reflector position

https://www.gsc-europa.eu

https://ilrs.gsfc.nasa.gov/



1. Metadata status

Content definition

- 2011 Content defined by the Galileo Scientific Advisory Comitte and requested to European Comission (EC)

Release through ILRS web site

- 2011 IOV (GSAT101-104) release of IOV Center of Mass (CoM)
- Onwards: continuous mass and CoM information update for all new satellites and after maneuvers

Release though GSC web site

- 2016 IOV (GSAT101-104) values for CoM, NAVANT, Geometry, Delays, attitude
- 2017 FOC (GSAT201-214) values for CoM, NAVANT, Geometry, attitude
- 2019 FOC (GSAT215-222) values for CoM, NAVANT
- 2022 FOC (GSAT223-224) values for CoM, NAVANT
- Onwards: mass and CoM information update after maneuvers

2. Metadata content

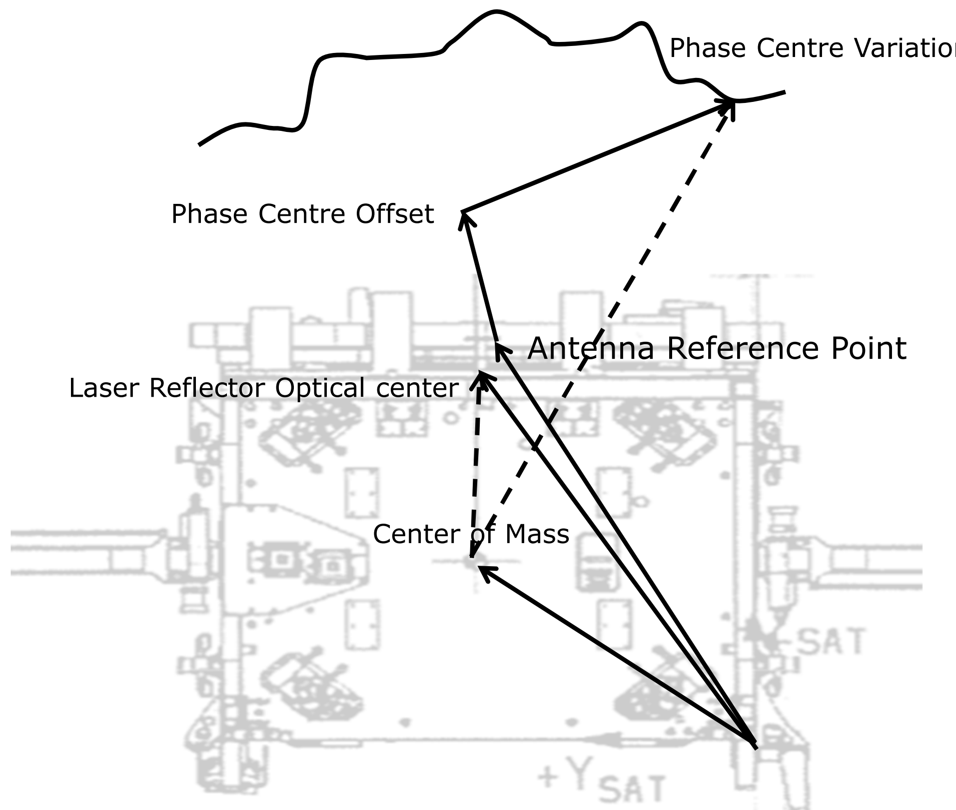
- List of required Galileo information for Scientific Applications

Area	Information	Format
Frame	Definition of body-fixed coordinate system (X,Y,Z) and view-cone angles (theta, phi)	definition
CoM	Mass and CoM evolution w.r.t. origin of mechanical reference frame	web site tables
NAVANT	Phase Center offset for each signal (E1, E5a, E5b, E5AltBOC, E6, ...) PCV for each signal (E1, E5a, E5b, E5AltBOC, E6, ...) as function of the view-cone angles (theta, phi), with respect the CoP	ANTEX
	Reference point for the Galileo navigation data message with respect the mechanical reference frame	ANTEX
	Antenna gain for each signal as function of the view-cone angles	Under preparation
Laser	Location of laser retroreflectors w.r.t. the mechanical reference frame	web site tables
Attitude	Nominal spacecraft attitude model, antenna pointing and solar array rotation Description of the satellite orientation during eclipses and "noon" rotations	equations
Geometry	Simplified face model with solar reflectivity, absorption and emission coefficients (e.g. based on configuration drawings including types of materials or surfaces) Dimensions of the main body and extensions (solar panels)	web site tables
HW Delays	Differential instrumental delays	web site tables

2. Metadata content

- Precise orbit determination requires linking observations centers and the dynamical model.

Area	
Frame	Vectors and orientation
CoM	Vectors and orientation
NAVANT	Vectors and orientation
Laser	Vectors and orientation
Attitude	Vectors and orientation
Geometry	Solar Radiation pressure model
HW Delays	Multifrequency



2. Metadata content: Mass and Center of Mass

Mass and one vector:

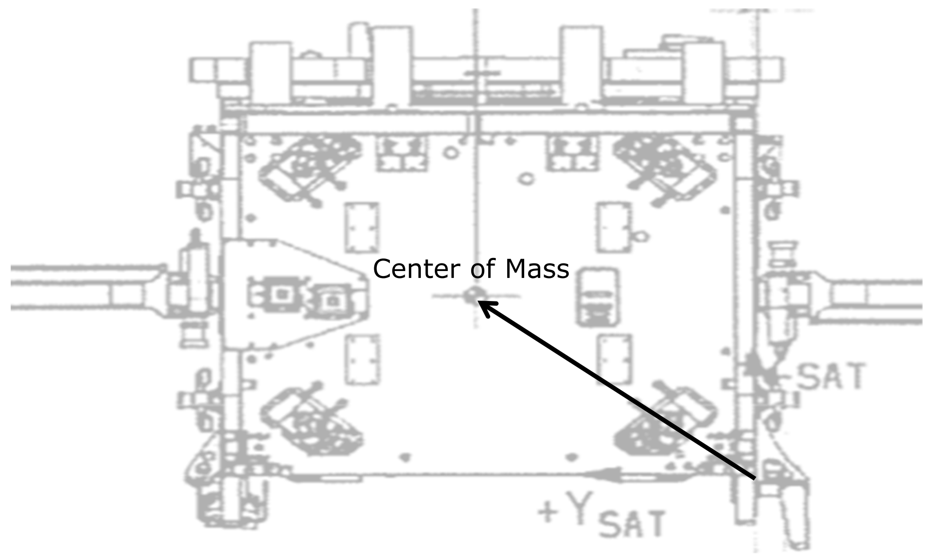
- Mass [Kg]
- Center of Mass vector in body frame [mm]

https://www.gsc-europa.eu

4.2 FOC Satellites

COM and mass of FOC satellites as of March 2022:

GSAT	Mass [Kg]	Centre of Mass		
		X [*mm*]	Y [*mm*]	Z [*mm*]
0201	660.977	316.89	-13.48	561.92
0202	662.141	311.61	-12.60	562.31
0203	705.685	259.54	-9.24	561.17
0204	697.701	269.65	-9.35	561.29



2. Metadata content: Centre of Mass (dry)

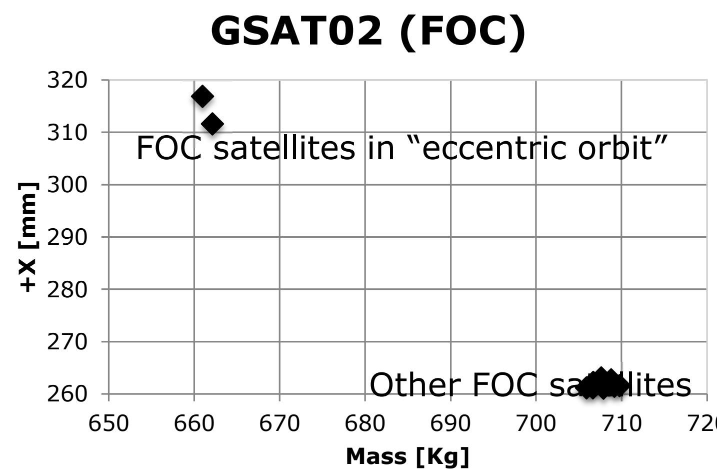
Dry measurement

- Flight configuration
- No propellant
- Stow configuration

2. Metadata content: Centre of Mass (wet)

Measured by test for each satellite:

- CoM = Measure in stow + (deployed – stowed panels) +(filled – used propellant)
- GSAT0201 and -02 in “eccentric” orbit show the displacement in + X when propellant is used
- Mass and CoM information is released after each launch and maneuver

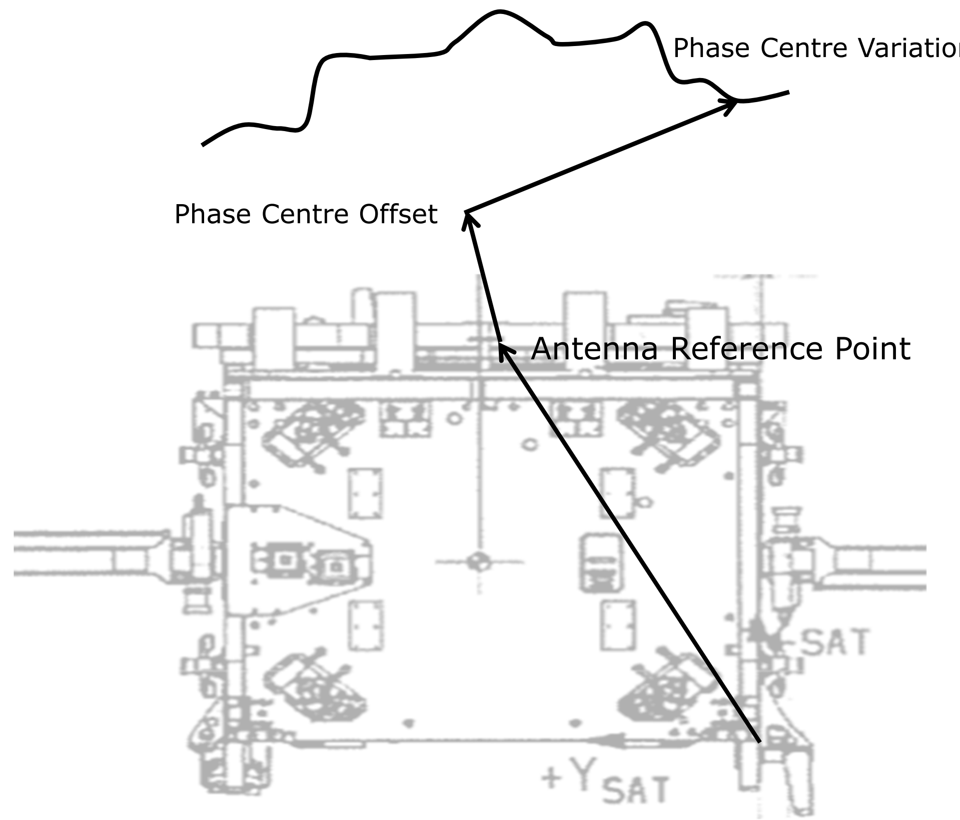


2. Metadata content: Navigation Antenna

Three vectors:

- Antenna Reference Point [mm]
- Phase center offset [mm]
- Phase Center Variation [mm]

https://www.gsc-europa.eu



5. Navigation Antenna Phase Centre Corrections

While the satellite motion is defined with respect to the Centre Of Mass (COM), the mean phase Centre is defined with respect to other point, the Antenna Reference Point (ARP). The difference between both points (mean phase centre and ARP) is known as the Phase Centre Offset (PCO).

5.1 Antenna Reference Point (ARP)

GSAT	ARP in mechanical RF [mm]		
	X	Y	Z
0101	1375.50	600.00	1100.50

GSAT	ARP in mechanical RF [mm]		
	X	Y	Z
0201	140.00	0.00	1215.00

5.3 ANTEX PCVs

The variation of the electrical phase centre of the antenna with respect to the mean phase centre, for a given direction, is called "Phase Centre Variation" (PCV). Direction-Dependant PCVs can be found in the GALILEO ANTEX file. In order to obtain the ANTEX file please click on the following link.

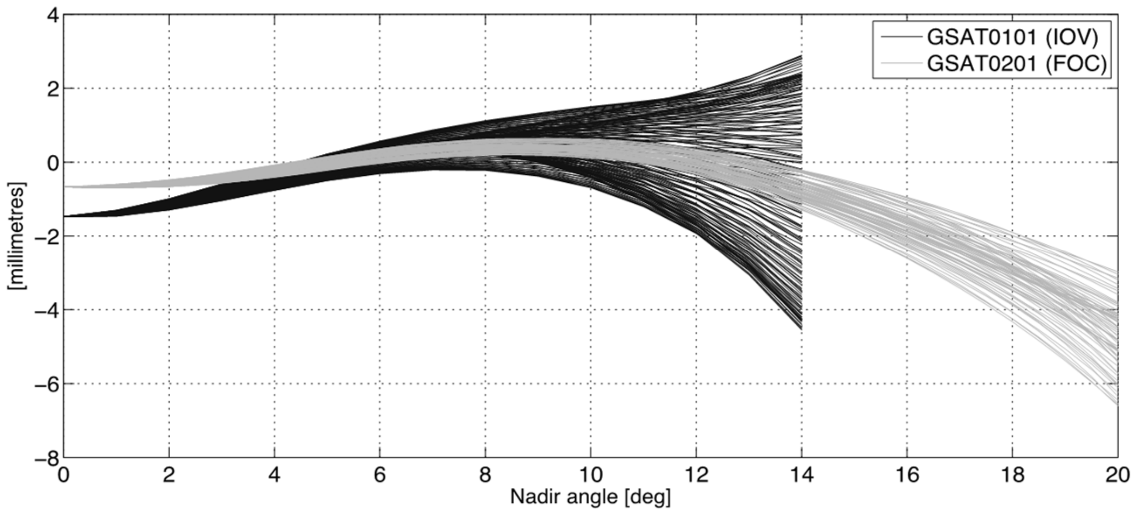
For GSAT01 (IOV) the PCVs are given for a 181 x 15 grid of azimuth and nadir angle pairs with a step size of 2° in azimuth and 1° in nadir. For GSAT02 (FOC) the PCVs are given for a 73 x 41 grid of azimuth and nadir angle pairs with a step size of 5° in azimuth and 0.5° in nadir.

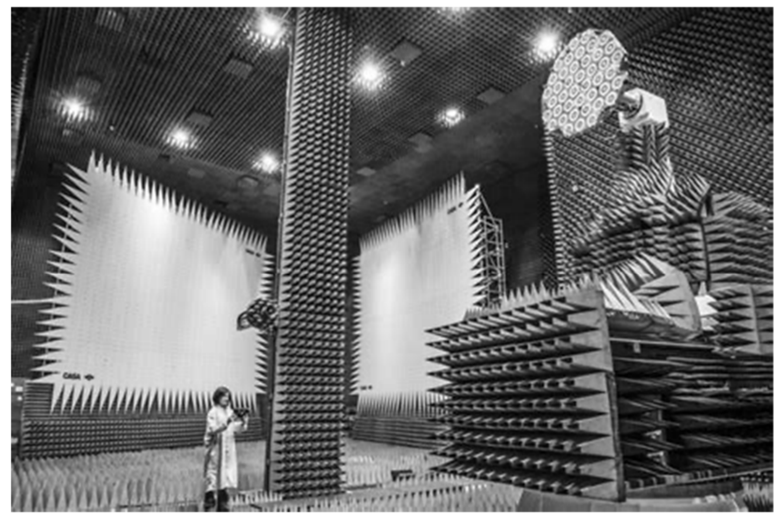
https://www.gsceuropa.eu/sites/default/files/sites/all/files/GSAT_2187.atx

2. Metadata content: Antenna Phase Center

Phase Center Offset and Variation measured in anechoic chamber <u>for each antenna</u>

- Azimuthal [0°,360°] and Zenith values from 0-14° (GSAT01) and -20° (GSAT02)





2. Metadata content: Laser Reflector

One vector:

- Optical center of the laser reflector array [mm]

https://www.gsc-europa.eu

7. Laser Retro Reflector Location

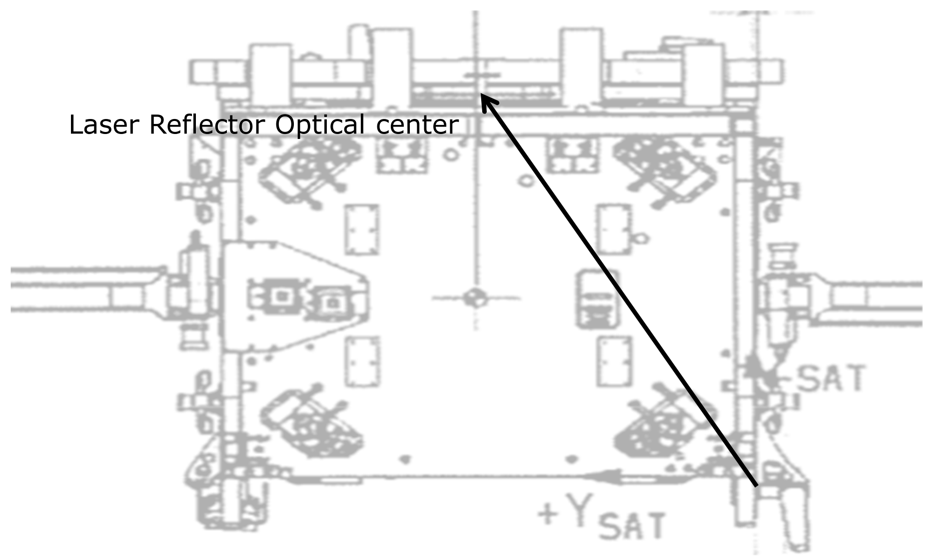
The center of phase of the LRR (Laser Retro Reflector) is provided in the tables below.

7.1 IOV Satellites

GSAT	LRR in Mechanical RF [mm]		
	X	Y	Z
0101	2298.00	595.00	1174.00

7.2 FOC Satellites

GSAT	LRR in Mechanical RF [mm]		
	X	Y	Z
0201	-703.00	-27.50	1120.45



2. Metadata content: Attitude

Content: attitude law equations

- Nominal law
- Modified law at low beta angles to keep the rate low for reaction wheels

3. Attitude Law

3.1 Yaw Steering Law

The nominal Galileo spacecrafts attitude is as follows: the body is fixed in a way it keeps the Z axis towards the Earth Centre (in order to illuminate the Earth with its Navigation Antenna), the Y axis is perpendicular to the Sun and the X axis points towards deep space. Please take into account that this does not meet the GPS block II/IIA attitude convention. It is important to keep the clock panel toward Deep Space so it is protected from the Sun, avoiding thermal variation.

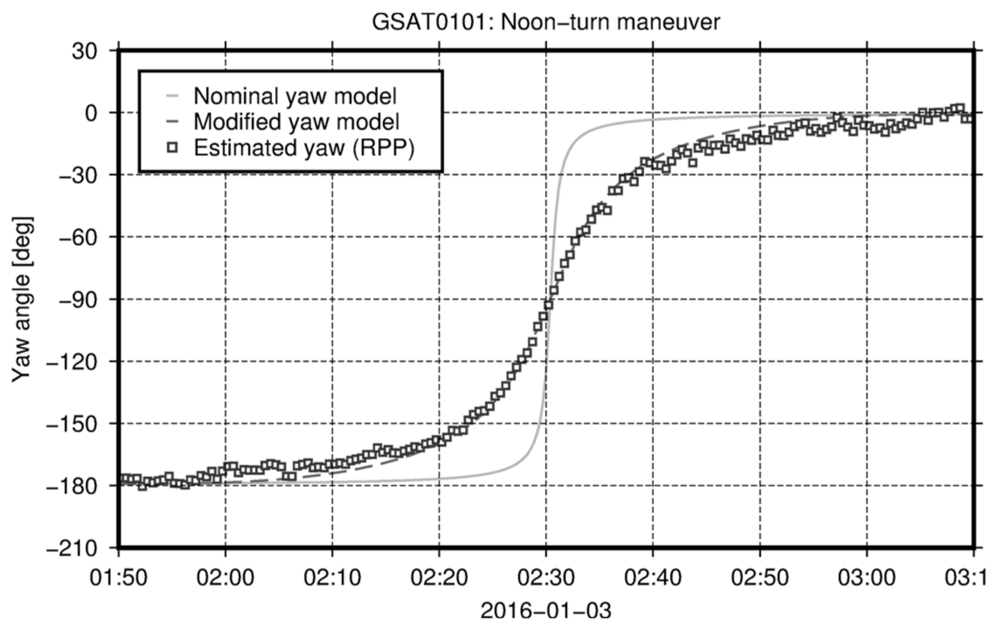
In order to maintain the nominal attitude it is necessary to turn ("yaw") about its Z axis while rotating its solar panels around the Y axis.

The required rotation is defined with respect to an orbital RF (Reference Frame). The orbital RF has its +Z-axis pointing towards Earth Centre, the +Y-axis perpendicular to the orbital plane ("across- track"), and the +X-axis completing the right-handed orthogonal system and pointing mainly in the flight direction ("along-track"). The yaw steering angle (Ψ_r) is defined as follows:

For the FOC satellites the yaw steering formula is as follows:

$$\psi(t) = atan2[\vec{s}(t)\cdot\vec{n}(t),\ \vec{s}(t)\cdot\vec{r}(t) \times \vec{n}(t)]$$

$$\psi_{mod}(t_{mod}) = 90deg \cdot sign + (\psi_{init} - 90deg \cdot sign)cos(2\pi/5656s\, t_{mod})$$



[1] *Source: F.Dilssner, Galileo IOV Spacecraft Metadata and Its Impact on Precise Orbit Determination, EGU2017*

2. Metadata content: Geometry

- Satellite Dimensions
- Optical properties

6. Geometry

The Galileo spacecraft is a typical "box-wing" type satellite, consisting of a central cube (the "box") and two rectangular solar panels (the "wings") attached to it. Due to the way the attitude of the spacecraft is controlled, only three of the six satellite panels are actually exposed to solar radiation: the −X panel, the −Z panel and the +Z panel. (Note EOL means "End Of Life" and BOL means "Beginning Of Life").

The optical properties coefficients are: $\alpha \equiv$ absorption coefficient, $\rho \equiv$ specular reflection coefficient, $\delta \equiv$ diffuse reflection coefficient.

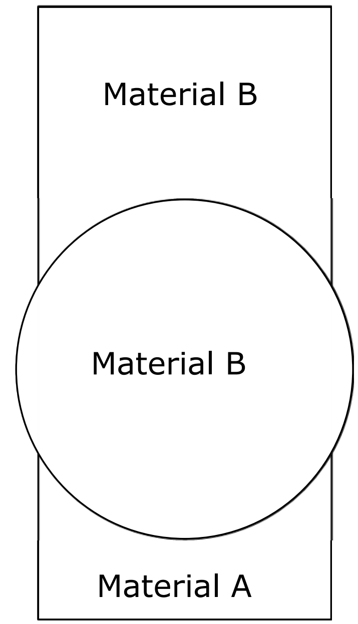
The surface area of each solar array amounts to 5.41 m^2 (= 5.000 m x 1.082 m).

Material	Area $[m^2]$	$\alpha[-]$	$\varrho[-]$	$\delta[-]$
A	1.053	0.93	0.00	0.07
B	1.969	0.57	0.22	0.21

https://www.gsc-europa.eu

Reality

Box-Wing



2. Metadata content: Differential code bias

Measured on ground by manufacturer for each satellite

- Calibration performed in ambient
- Sensitivity to temperature measured on thermal chamber

https://www.gsc-europa.eu

8.2 Differential Code Bias

Median values and standard deviations of these (hourly) DCBs estimates are given in the Table below. The standard deviations point to a DCB stability of about $\sigma = \pm 0.1m$ (0.3 ns). Evidence for the existence of thermal-dependent fluctuations, as detected in tri-carrier combinations computed for the GPS Block IIF spacecraft series while passing through eclipse season, was not found.

>

GSAT	E1-E5a		E1-E5b		E1-E6	
	[ns]	*[m]*	*[ns]*	*[m]*	*[ns]*	*[m]*
0101	9.71±0.38	2.910±0.115	9.77±0.32	2.929±0.095	6.32±0.37	1.894±0.111
0102	6.97±0.41	2.089±0.122	6.87±0.33	2.060±0.099	7.41±0.30	2.220±0.90
0103	2.15±0.48	0.644±0.144	2.11±0.39	2.634±0.117	-0.77±0.31	-0.230±0.094
0104	2.14±0.39	0.641±0.116	2.15±0.50	0.644±0.150	1.82±0.25	0.546±0.076

3. Scientific benefit

- Values adopted by the Scientific community for Precise Orbit Determination
- Allowed for a significant improvement of geodetic Galileo products which is highlighted by a number of scientific papers.
- The availability of ground calibrated phase centre offsets and variations for the full Galileo constellation makes it possible for the first time to contribute with GNSS to the scale of the International Terrestrial Reference Frame (ITRF).
- For the generation of the ITRF2020, the Galileo scale was not yet considered, however, a good consistency with the VLBI scale could be demonstrated. This progress would not have been possible without the publication of the Galileo metadata. Science community is very grateful for this step.
- With future updates further improvement will be possible.

4. Metadata future improvements

- Additional recommendation by the Galileo Scientific Advisory Comitte for updated content

Satellite model	Higher level of details concerning different materials used on the different satellite surfaces (area, optical properties, including nominal uncertainties), including front and back side optical properties for solar arrays.
	Infrared optical properties of surface materials for modelling of thermal Earth radiation effects.
	Transmit power for the calculation of the antenna thrust.
	Radiator emission power (at least mean value) for the different surfaces to allow for the calculation of the corresponding thrust.
	Thermal properties of solar arrays (temperature and emissivities of front and back sides, thickness, heat capacity) for modelling of re-radiation thrust in particular during shadow transits.
	Thermal properties of the navigation antenna (temperature range, emissivity, heat capacity) for computing the variable radial thermal thrust.
	Thermal properties of the laser retro reflector array (temperature range, emissivity, heat capacity).
Attitude	Information about the actual yaw turn switching epochs is needed to model the satellite orientation at these dates.
clock	Notification of the active clock with corresponding time intervals also for the past to support reprocessing activities.
	Ground test data for the clocks in space, characterizing the expected clock performance.
NAVANT	Phase centre offsets used for the generation of the broadcast orbits for the different services.
	Transmit antenna group delay variations and nadir patterns.
	Transmit antenna gain pattern for boresight angles up to 90 degrees.
Accuracies	Nominal accuracies of the metadata provided helps to assess the uncertainties of derived models of non-gravitational orbit perturbations.

5. Conclusions

Status

- Data set with the relevant Satellite properties for Precise Orbit Determination
- Defined by the Scientific community through the Galileo Scientific Advisory Committee
- Released and regularly updated from 2011 through GSC and ILRS web sites
- Galileo was the first GNSS for which metadata was made publicly available
- New additional content being defined with the scientific community.

Scientific community benefit

- Most of the values adopted by the Scientific community for POD
- Allowed for a significant improvement of geodetic Galileo products
- Allowed for first time to contribute with GNSS to the scale of the International Terrestrial Reference Frame (ITRF).
- Further benefits possible with further information